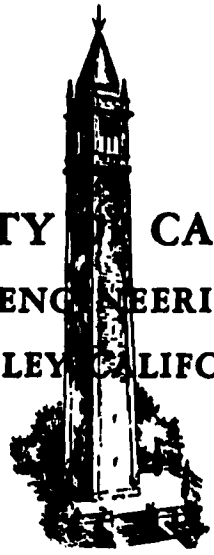

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Discussion of Paper
"CREEP BEHAVIOR OF EXTRUDED ELECTROLYTIC MAGNESIUM" by C. S. Roberts
Journal of Metals, AIME, September 1953, pp. 1121-1126

Thirty First Technical Report

By

O. D. Sherby and R. E. Frenkel

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* * * * *

We wish to congratulate Dr. Roberts on his interesting contribution to the literature on creep. Although Dr. Roberts' conclusions appear in part to be substantiated by his experimental results, alternative interpretations appear to be worthy of consideration.

1. Dr. Roberts suggests that primary and secondary stages of creep arise from two independent phenomena. This is in agreement with Andrade's original ideas[1] on transient and quasi-viscous (steady-state) creep. McLean's investigations on aluminum[2,3], however, clearly reveal that the main processes of deformation, i.e. migration of dislocations and grain boundary shearing, occur during primary creep as well as during secondary creep. Therefore the transient and steady-state components of creep cannot be ascribed to migration of dislocations and grain boundary shearing respectively.

2. Dr. Roberts indicates that steady-state creep becomes predominant at high temperatures whereas transient creep is predominant at low temperatures. Other evidence[4,5], however, strongly suggests that stress and not temperature is the important factor in determining the shape of the creep curve. In recent investigations[4,5] it has been shown that the creep strain, ε, at high temperatures, can be correlated by means of the functional equation

$$\varepsilon = f(\theta, \sigma) \qquad (1)$$

where σ = creep stress and $\theta = te^{-\Delta H/RT}$ where t = time under stress, ΔH = activation energy for creep, R = gas constant and T = absolute

temperature. Thus at a given stress σ , the creep strain-time curves at various temperatures can be correlated by means of the parameter θ . An example of this correlation for the creep of high purity magnesium under a constant load of 2500 psi, is reproduced in Fig. 1. It will be observed that the 401°F and 496°F tests superimpose well for all three stages of creep yielding an activation energy of 34,000 calories per mole. These data suggest that the temperature does not determine the shape the creep curve and that the separation of a creep curve into two distinct components, each of which have markedly different temperature dependence, is untenable.

3. We question the validity of drawing breaks in the isothermal curves of the stress-secondary creep rate plots in Roberts' Figs. 4 and 5. With the possible exception of the 600°F data curvilinear lines would appear equally justified. Furthermore, on the basis of equation (1), the stress-secondary creep rate data can be correlated by means of a single parameter $\dot{\varepsilon} e^{\Delta H/RT}$, since as previously proven[4,5]

$$\sigma = F(\dot{\varepsilon} e^{\Delta H/RT}) \qquad (2)$$

where σ is the stress and $\dot{\varepsilon}$ is the secondary creep rate. This method of correlation was applied to the data reported in Roberts' Figs. 4 and 5. As shown in our Figs. 2 and 3 these data correlate very well assuming an activation energy of 31,000 calories per mole in good agreement with the 34,000 calories per mole value obtained in our Fig. 1. It will be observed that Roberts' datum point at 1000 psi, 300°F veers to the right of the main curve; this is possibly due to the fact that at this low stress the secondary stage was not yet reached for the duration of testing and consequently the rate was faster than the actual secondary creep rate.

4. Dr. Roberts' analyses on transient creep suggest an activation energy of 15,500 calories per mole. This was deduced by observing a

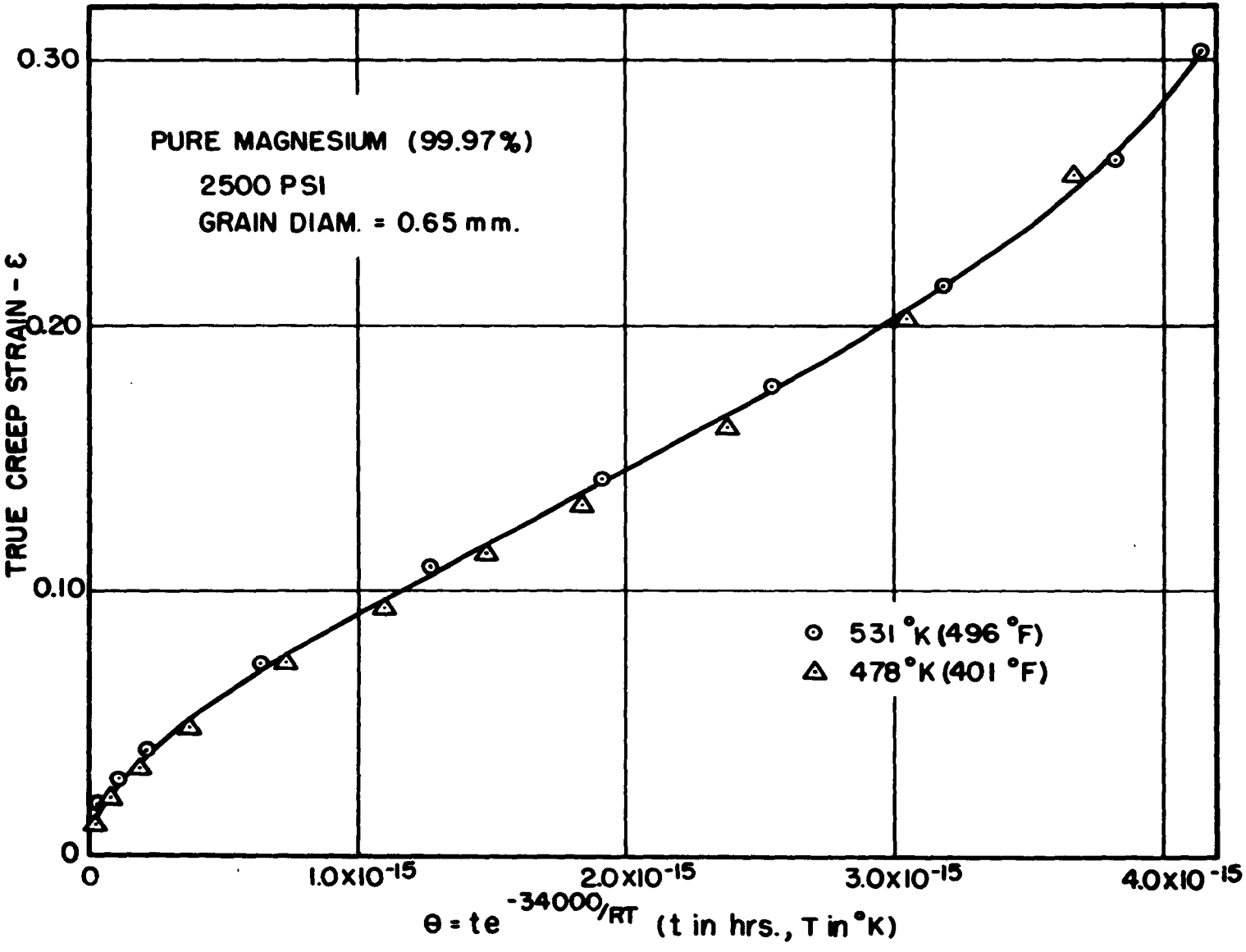

FIG. 1 CORRELATION OF CREEP STRAIN - TIME DATA FOR HIGH PURITY MAGNESIUM BY THE RELATION $\varepsilon = f(\theta)$ AT A STRESS OF 2500 PSI.

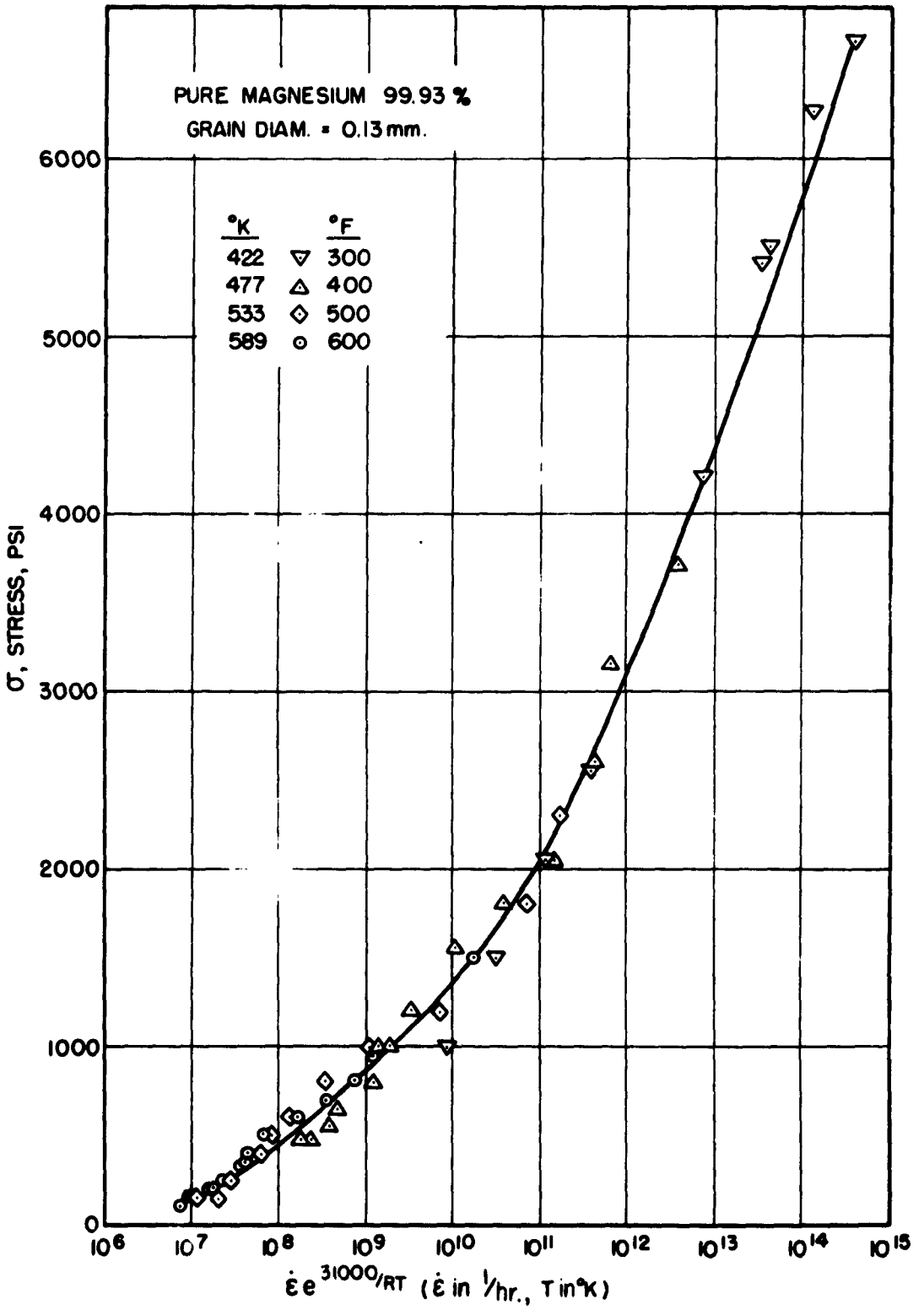

FIG. 2 CORRELATION OF STRESS - SECONDARY CREEP RATE DATA FOR PURE MAGNESIUM BY THE RELATION $\sigma = f(\dot{\varepsilon} e^{\Delta H/RT})$.
(DATA FROM ROBERTS' FIGS. 4 AND 5)

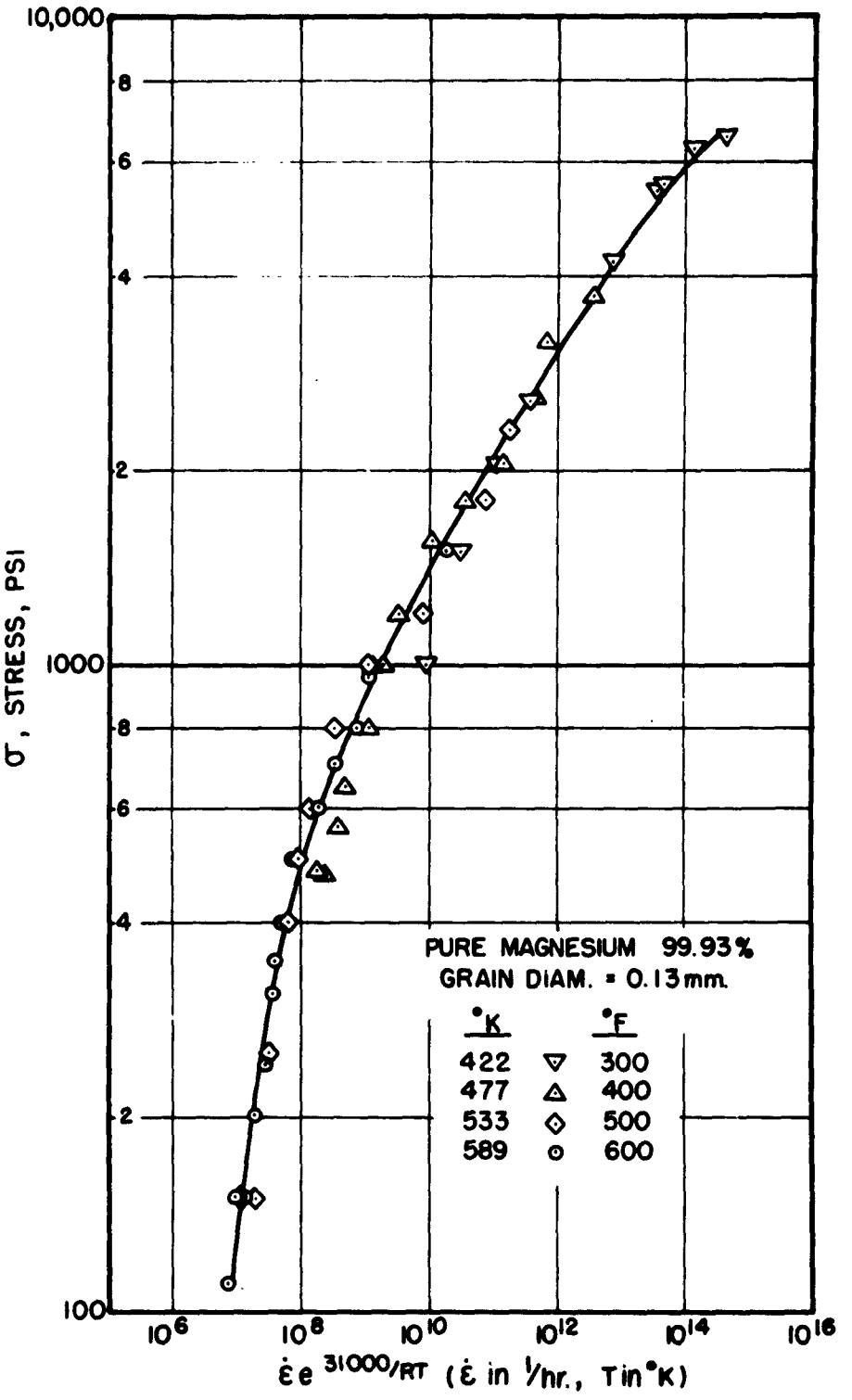

FIG. 3 CORRELATION OF STRESS- SECONDARY CREEP RATE DATA FOR PURE MAGNESIUM BY THE RELATION $\sigma = f(\dot{\varepsilon} e^{\Delta H/RT})$.
(DATA FROM ROBERTS' FIGS. 4 AND 5)

straight line relationship between β (from the empirical relation $\varepsilon = \beta t^n$) and the reciprocal of the absolute temperature at a given stress. But β is simply the value of the creep strain at one hour; consequently, the strained states that are being compared by this procedure are different for each temperature and therefore the activation energies so obtained are fictitious. The results shown in our Fig. 1 reveal that the activation energy for transient creep is no different from the activation energy for secondary creep, which furthermore should equal the activation energy for self-diffusion[5].

The ΔH values during transient creep can also be obtained from Roberts' data. Interpolation of the data in Table I and Fig. 7 yields $\beta = .084$ at 2500 psi and 500°F, which also represents the strain at 1 hour under these test conditions. In Roberts' Fig. 2 extrapolation of the 400°F, 2500 psi data to $\varepsilon = 0.084$ indicates that the time to reach this strain equals about 30 hours. Therefore, from equation (1)

$$\Delta H = \frac{R \ln t_1/t_2}{\frac{1}{T_1} - \frac{1}{T_2}} = \frac{4.6 \log_{10} \frac{30}{1}}{\frac{1}{477} - \frac{1}{533}} = 31,000 \text{ calories per mole.}$$

The same answer was also obtained in comparing the 400°F and 500°F data at 1000 psi. These results yield further evidence that the activation energy for the so-called transient creep is essentially equal to that for steady-state creep.

5. Dr. Roberts suggests that the transient stage of creep arises solely from intragranular processes of basal slip and subgrain formation, whereas steady-state creep results from a cyclic process of sliding and migration of grain boundaries. McLean's results[3] on the creep of aluminum during secondary creep however indicate that the contribution of grain boundary shearing was never greater than a few percent of the total

strain, the main contribution to creep being crystallographic slip. He also showed that the strain due to grain boundary shearing exhibited primary and secondary creep characteristics similar to those exhibited by the total creep strain. Furthermore, Chaudhuri, Grant and Norton[6] obtained extensive basal slip and subgrain formation at about 600 psi and 500°F for high purity magnesium throughout the whole creep curve.

6. It is surprising that the size of subgrains formed during creep of magnesium remains constant independent of all test conditions investigated. Recent investigations on aluminum by Servi, Norton and Grant[7] as well as by Sherby and Dorn[8] indicate that for a constant amount of deformation the size of subgrains depends solely on the stress level independent of temperature. At high stresses the subgrains were very fine and at low stresses very coarse.

ACKNOWLEDGMENTS

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